ARPA-E INTEGRATE Program Review

Hybrid Electric Aircraft Design Space, Feasibility and Technical Challenges

18 September 2019

Ram Ranjan

UTC Power Generation Portfolio

Leader in aerospace power generation from 100 kWs to > MW

Primary Power Generation

B787 250 kW

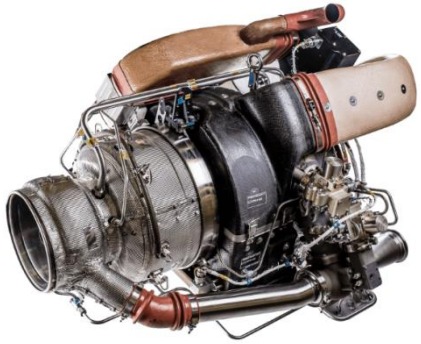
Military 80 kW*

*http://www.inovasyon.org/pdf/NAP.Com.Aircraft.Prop.&Energy.Systems.Research.2016.pdf

Low Weight & Cost
Medium efficiency

Secondary/ Auxiliary Power Generation

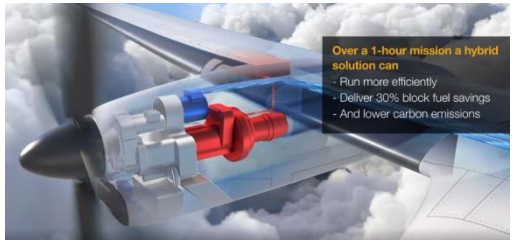
B787 400 kW



A320 90 kW

Low Weight & Cost
Low efficiency

Hybrid Propulsion



Reduce carbon emissions

100 kW - MW

Low weight

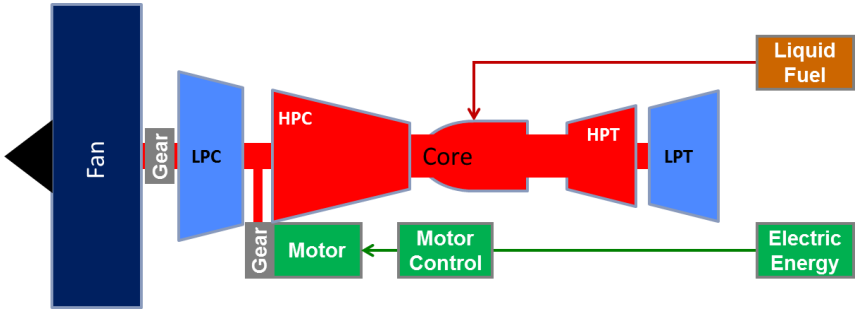
High efficiency

Enable distributed propulsion

Electrified Propulsion (EP) System Architectures

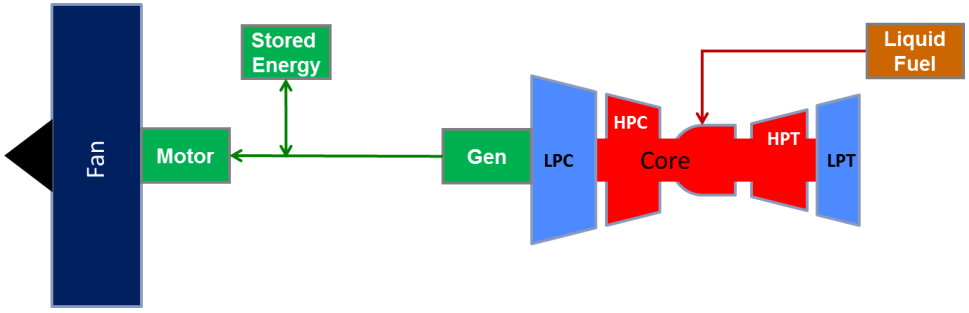
4 basic configurations

Parallel Gas-Electric Hybrid



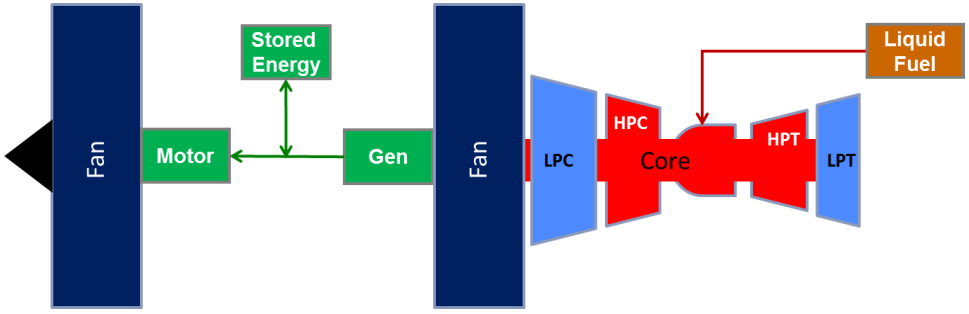
All thrust from main fans, fan power from liquid fuel through GT and battery though LS motor

Full Series Turboelectric Hybrid



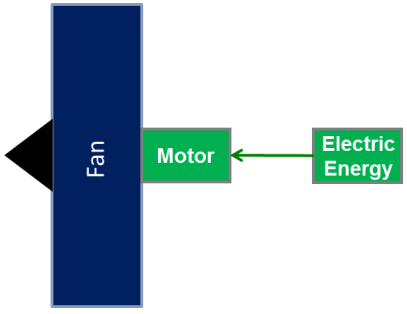
GT creates electric power from liquid fuel, electric power distributed to multiple electric fans for thrust, battery used load leveling

Partial Series Turboelectric Hybrid



Full Series Turboelectric Hybrid, with addition of thrust from GT LS fan

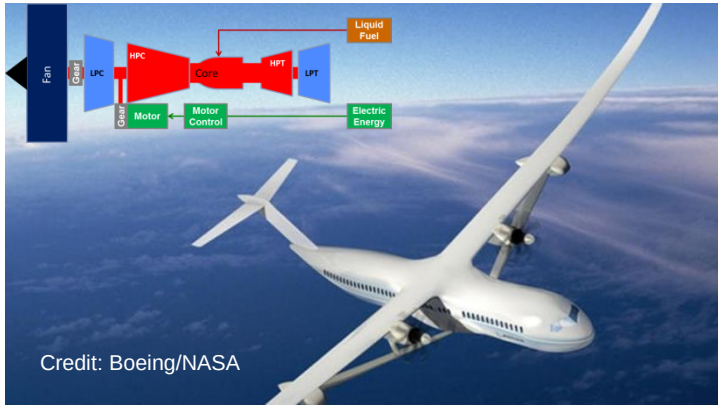
All Electric (not a Hybrid)



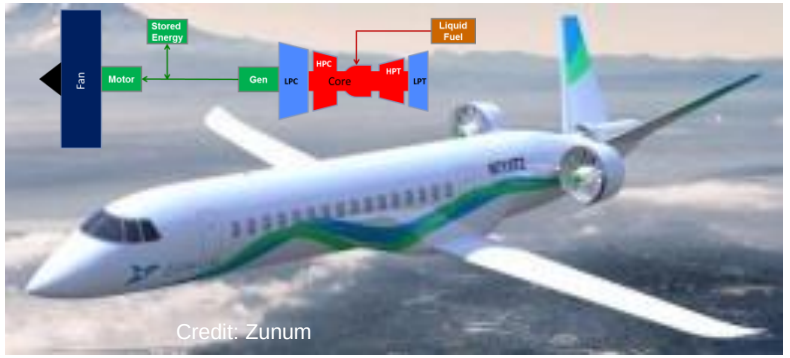
Electric power from battery distributed to multiple electric fans for thrust

Electrified Aircraft Propulsion (EAP) Concepts

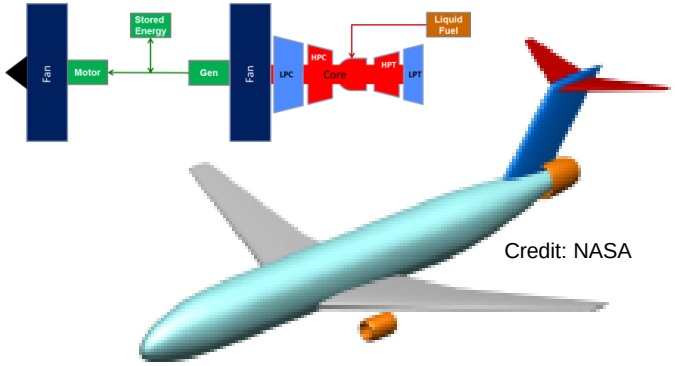
Example EP implementations



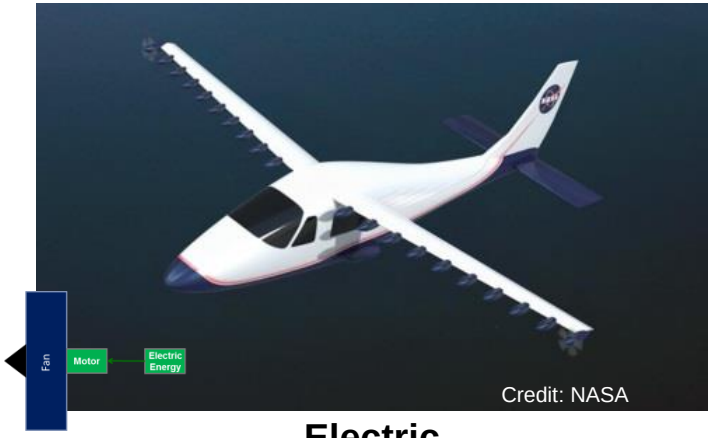
Parallel Gas-Electric Hybrid



Full Series Turboelectric Hybrid



Partial Series Turboelectric Hybrid

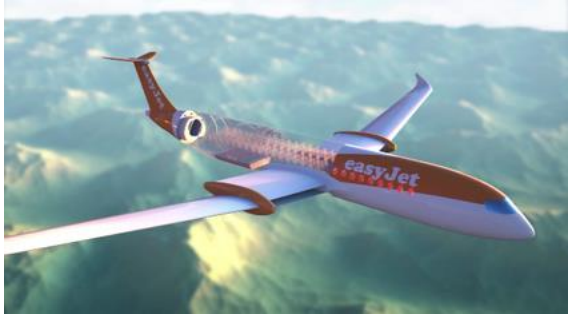


Electric

Why Hybrid Electric

Enables New Missions

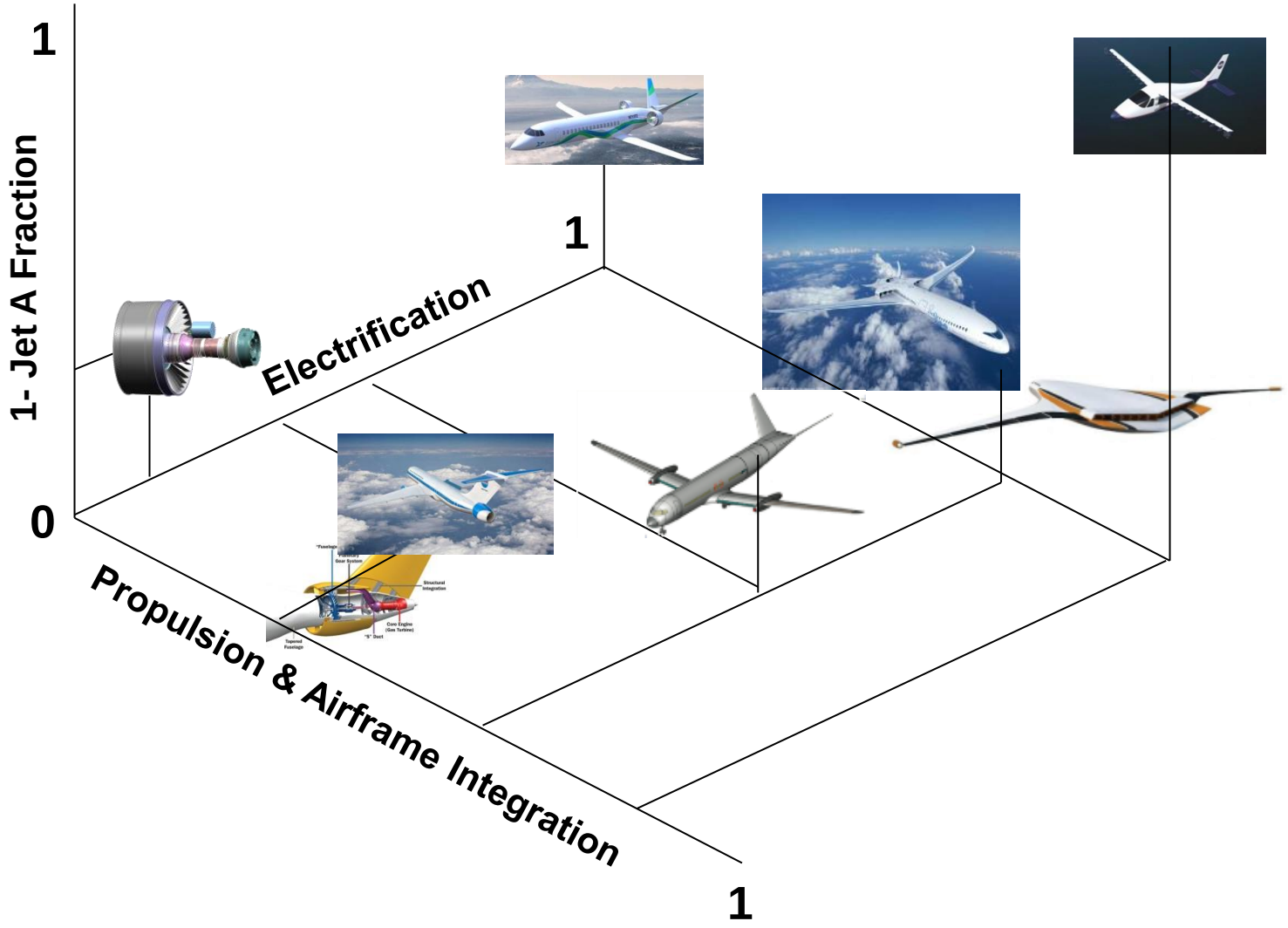
Enables New Business Models



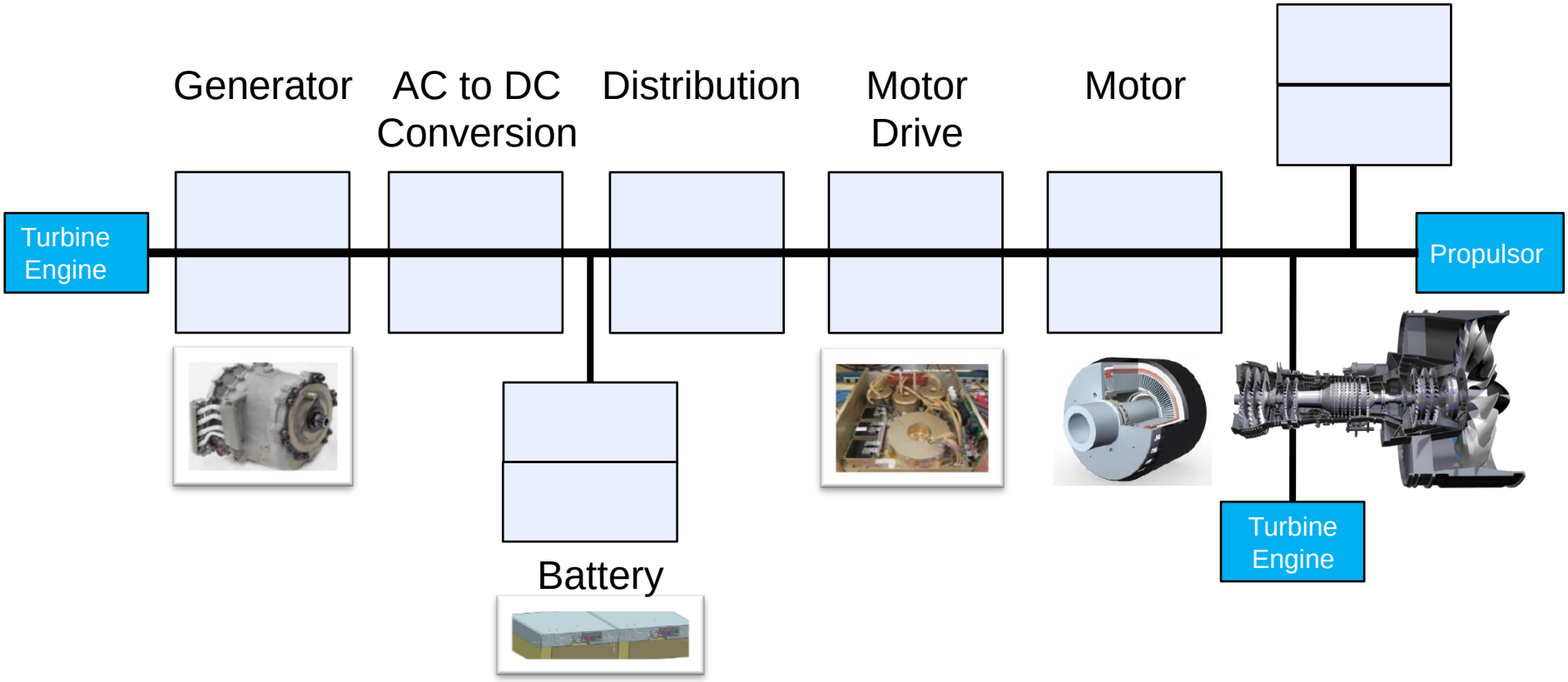
Enables Fuel Burn & CO2 Reduction

Hybrid Electric Aircraft Design Space

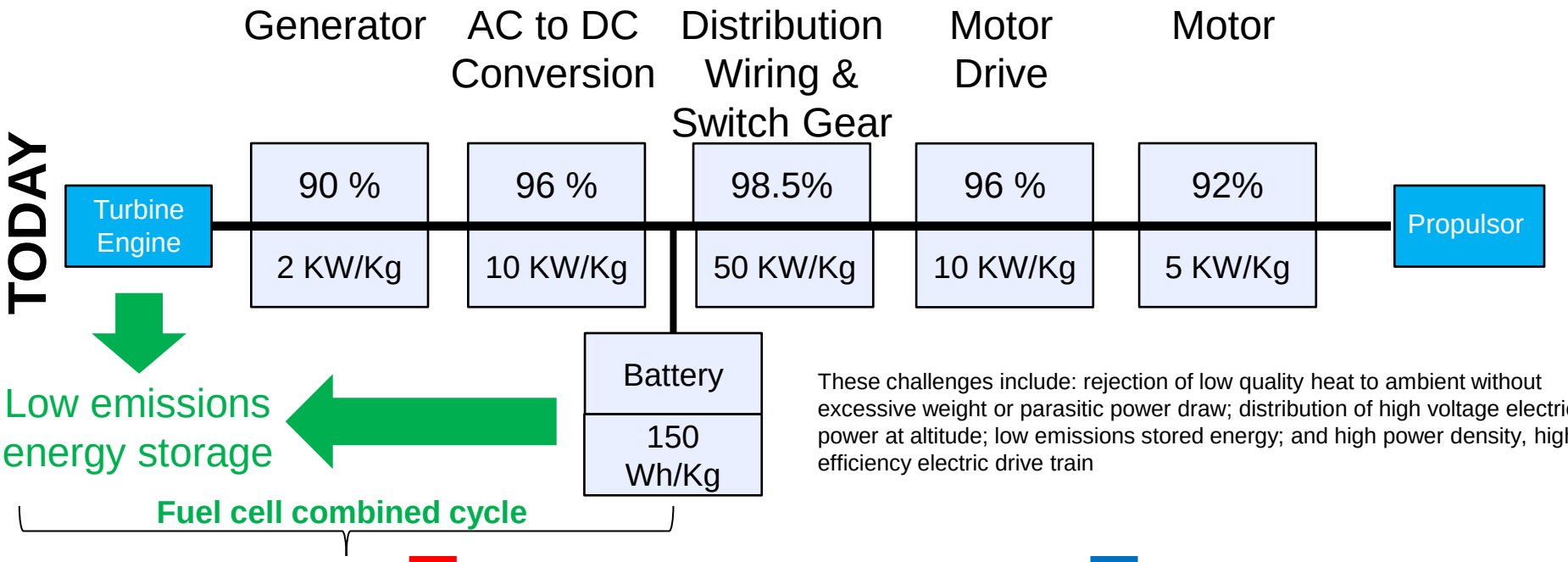
Point studies done in the design space



EAP Drive Train



Drive Train Challenges



These challenges include: rejection of low quality heat to ambient without excessive weight or parasitic power draw; distribution of high voltage electric power at altitude; low emissions stored energy; and high power density, high efficiency electric drive train

Medium to Low Quality Waste Heat

- Weight – Fuel cell stack, reformer, heat exchangers, ducts, plumbing
- Ram Drag – Battery cooling
- Power – Pumps, Fans, VCS?

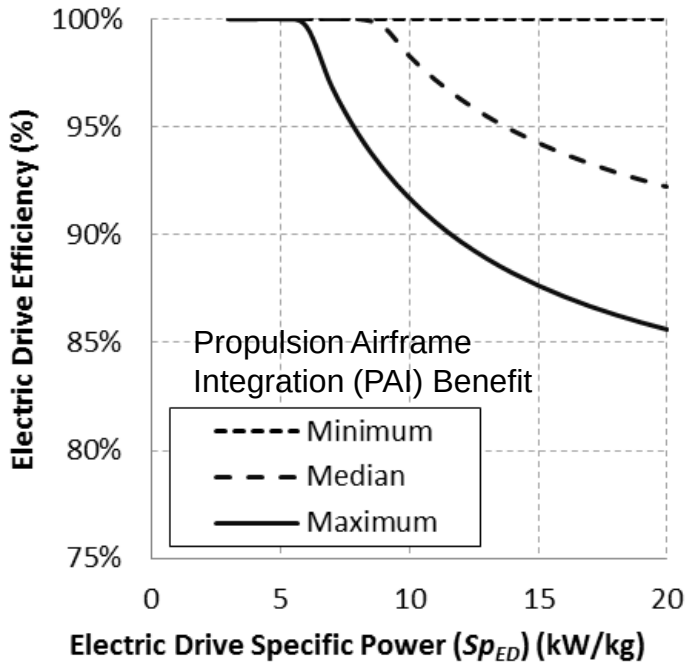
Power Train

- Weight – EM Machines, PE & Distribution
- <u>High voltage – switches and protection</u>
- Power – Losses increase power and energy requirement, create heat

Series Turboelectric Hybrid

Series hybrids include an electric drive that must buy its way on the system

Series turbo-electric hybrid



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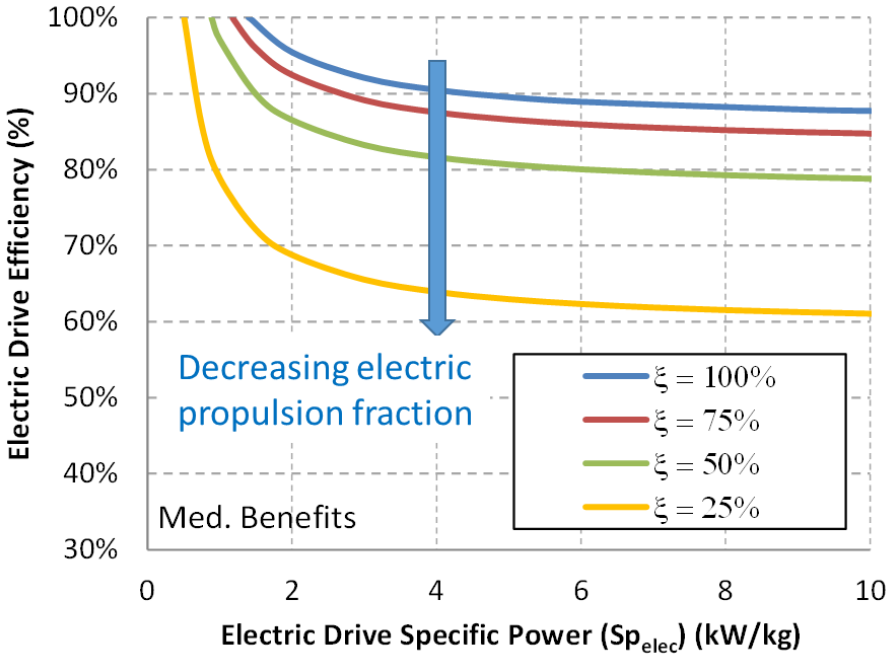
Partial series turbo-electric hvbrid



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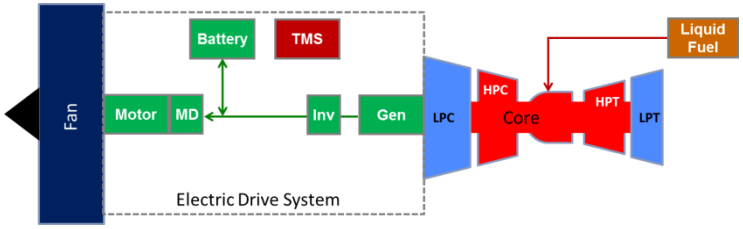
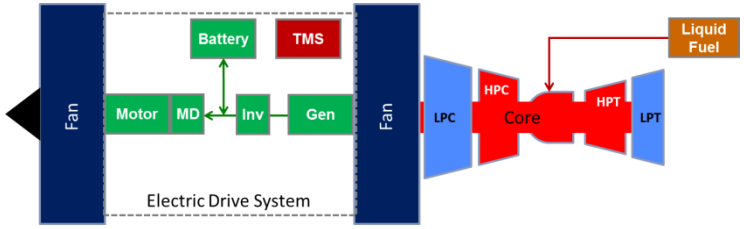




Electric Drive Train (EDT) Performance

Current development progressing toward 2.1 kW/kg @ 86%

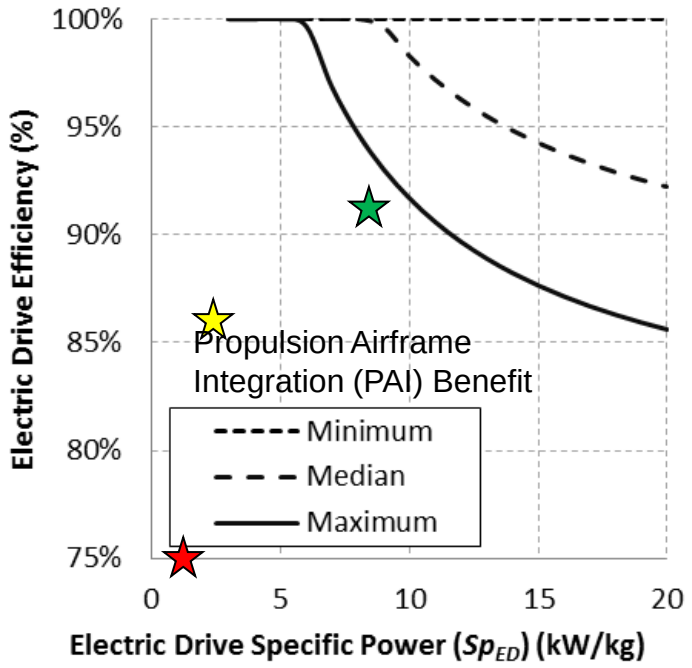
Today	Current Progress	Future Targets
0.9 kW/kg, 75%	2.1 kW/kg, 86%	8.4 kW/kg, 91%

	Today		Near Term Current Programs		Future Investment	
	Efficiency	Power Density	Efficiency	Power Density	Efficiency	Power Density
Components		kW/kg		kW/kg		kW/kg
Generator	90.0%	2	94.0%	4	96.0%	40
Rectifier	96.0%	10	98.0%	20	99.0%	40
Distribution	98.0%	50	98.5%	50	99.0%	100
Motor Drive	96.0%	10	98.0%	20	99.0%	40
Motor	92.0%	5	97.0%	13	98.0%	40
Thermal		1		4		10
Total	**75%**	**0.9**	**86%**	**2.1**	**91%**	**8.4**

Benefit of Improved EDT Performance

Future EDT improvements can enable PAI benefit

Series turbo-electric hybrid



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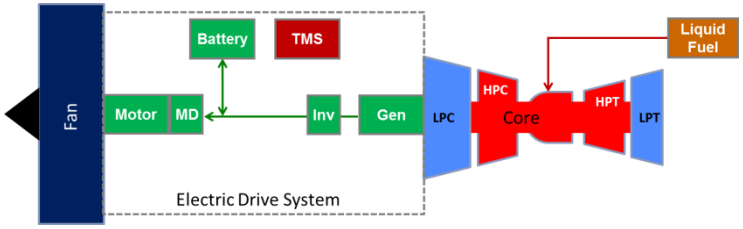

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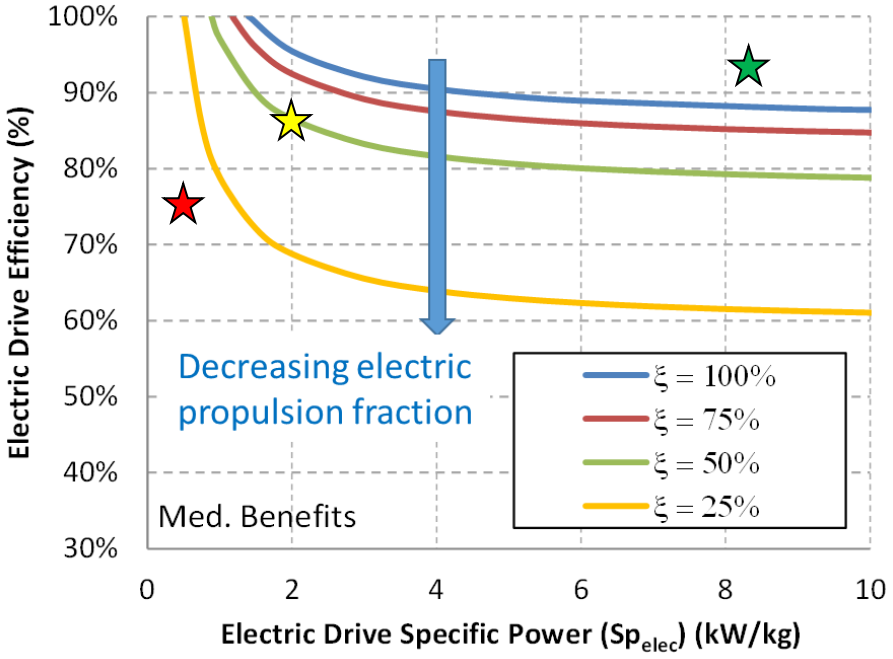

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